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CERTAIN UNDETERMINED FACTORS IN HEREDITY AND ENVIRONMENT.

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IN a paper read before the Botanical Section at the Pittsburg meeting of the American Association for the Advancement of Science [1] I suggested that certain factors of the environment were constantly ignored in such discussions of heredity as I had seen or heard. This paper constitutes substantially the last section of my book.[2] Since certain letters which I have recently received, make me feel that in this section I have expressed myself so concisely that my full meaning is not altogether clear, I take this opportunity to give somewhat ampler treatment to the subject.

The word *environment* is used ignorantly by everyone, for no one has ever succeeded in making a complete analysis of what is meant by this collective term. Furthermore, although we speak of an organism as reacting to its environment, it does not react to its environment as a whole but to each of one of the separate influences which are the factors of its environment. It is, therefore, very important to know what these factors are, and what are their effects. We know that if two of these influences are opposite and equal, there will be no visible reaction, although the organism will be affected by both. There may be internal results of these influences, results which, however, may not be perceptible. If one of these opposite influences be lessened or eliminated, the effect of the other becomes perceptible. We judge, then, the influence of the various factors which we are now able to distinguish from one another as constituting the environment, only by their perceptible effects. It is conceivable that some effects are so long deferred that they are coincident or at least contemporaneous with the effects of other and more recent stimuli. For this reason these long deferred effects may easily be overlooked, or they may be perceived only incompletely and with difficulty, or they may be attributed to wrong causes. It is also conceivable that certain influences produce effects not because they are powerful, taking into account only short times of operation, but because they are prolonged.

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[1] Abstract in *Science*, XVI. p. 137, 1902.

[2] Peirce, G. J. *Text book of Plant Physiology*, 279–83, New York, 1903.

This leads us to essay an analysis of environment. The environment of an organism is all, everything, that constitutes the world and the universe outside of itself. One may say that this definition is too comprehensive, that only *immediate* environment is meant when the word environment is generally used. Who can say that organisms and things are affected *only* by their immediate environment? In fact we know that the contrary is true in certain particulars. We know, for instance, that we are daily affected by the sun — a remote body — quite as much as by any part of our immediate environment. But we do not know all the radiations and other influences from all the heavenly bodies in the universe, the effects of these upon our earth as a planet, and what is upon it; and yet these radiations still unknown and unguessed, together with other unknown and unguessed factors of environment, may operate as regularly and as powerfully as any of the known and recognized factors.

Among the recognized factors of the environment are some, the effects of which are very imperfectly known, if they may be said to be known at all. These will be seen in their relations to other factors if an analysis, however imperfect, of the environment be given. Thus

Environment — all that constitutes the universe.

1. *The earth* — soil, rocks, waters, atmosphere; the components, conditions, contours, etc., of these.
2. *All other planets* — whatever conditions prevail upon them; their relative positions to the earth and to each other.
3. *The forces* emanating from and operating upon these — heat, light, electricity, mechanical forces (gravity, wind, waves, rain, etc.).
4. *All living things* — their parts, products, and habits.

If we go through the list of factors suggested by this scheme, we shall see that, in spite of their diversity and oppositeness, we may bring them into an orderly classification. We may arrange them under these four headings — 1, unchanging, 2, variable, 3, occasional, 4, periodic. Among unchanging factors the following may be mentioned,[1] *viz.* the atmosphere, water, the force of gravity, the earth as a whole. Though these are not all of the unchanging influences I shall discuss only these four.

The earth's atmosphere, consisting of nitrogen (80%) and oxygen (20%), with only a small fraction of 1% of carbon-dioxide and other gaseous matters, possesses unchanging physical properties and exerts a pressure which varies only very slightly, taking only short intervals of time for the comparison, and varies not at all, taking long intervals of time. For example, the barometric pressures in any given locality are the same in this century as in the last, and though we may have "low" and "high" barometers at different times, these variations are very slight. The buoyancy, diversity, color, transparency, permeability, etc., of the earth's atmosphere are the same to-day as a "million" years ago, as far as we know, and though these qualities and the pressure of the atmosphere may change and may have changed during the lapse of the millions of years during which the earth is likely to exist and has existed as a planet, they are unchanging so far as millions of generations of living organisms, and so far as millions of series of lifeless things, are concerned.

The composition of the earth's atmosphere has changed but little, if at all. The proportion of carbon-dioxide may have been greater in an earlier time, but for uncountable ages the proportions have been what they are now. Let us suppose, however, that the proportions of nitrogen, oxygen, and carbon-dioxide have changed somewhat, taking the whole atmosphere into account, not a small part of it merely. If only the proportions were different, there would still have been nitrogen, oxygen, and carbon-dioxide in the air, and these gases themselves are unchanging. We cannot imagine some oxygen being any different from all oxygen; if we have carbon dioxide we have necessarily carbon-dioxide of the same composition and properties since the world began. The same of the inert gas nitrogen.

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[1] See p. 280 of my "Text Book."

When experiments are instituted for the purpose of eliminating these substances, they fail, for it is out of the question to remove all nitrogen, oxygen, and carbon-dioxide even if all N, O, and Co_2 can be excluded at the beginning of an experiment, for N and O will be contained in the organism and Co_2 will be formed by it. Nevertheless, the living organism which is dependent upon oxygen for respiration, upon nitrogen to dilute the otherwise too destructive oxygen, and upon carbon-dioxide from which to manufacture food, will succumb in any experiment of more than brief duration in which the proportions of these gases are greatly different from those in normal air. In other words the physical properties of the atmosphere, its components, their composition and proportions, being and having for ages been what they are, living organisms represent reactions to these qualities and will not bear sudden change, whatever might be or may have been the result of gradual change, if there has been any.

Water is composed of hydrogen and oxygen in the proportions of two to one. It always has had the same chemical composition, structure, and properties, the same physical qualities. It is an indispensable constituent of living organisms and of many lifeless things. It is a weak acid and the most universal solvent known. Molecules and atoms of dissolved substances move about in it with considerable freedom, and where two volumes of water are separated from one another only by permeable or semi-permeable membranes, there is molecular or atomic movement both of water and of dissolved substance from the one volume to the other through the membrane. Water is then a medium in which ampler molecular and atomic movements are possible at ordinary temperatures, etc., than in many other substances. But the movement of the molecules and atoms of the solutes are independent of, though taking place among, the water molecules. The water remains the same, physically and chemically, whatever substances may be dissolved in it. The temperature of a solution of small volume may be different while solution is taking place, but ultimately the temperature of the solution, or of water holding nothing in solution, will be approximately that of its surroundings, other things being equal. The specific gravity of the solution will differ from that of pure water, but the specific gravity of the water itself and of the solute itself are the same as they have always been, the specific gravity of the solution depending only upon these two.

With its physical and chemical properties unchanged, as an essential constituent of all living organisms and the medium in which necessarily the food materials and foods enter and move about and are chemically changed in the cell, water has exerted upon living things an influence as powerful and as persistent as have been its relations to the physical and chemical conditions and processes of lifeless substances since the beginning. Water can be eliminated neither outright nor by substitution from experiments with living organisms nor, for that matter, can it be eliminated from the majority of experiments with lifeless substances. It is a substance of universal occurrence, of uniform properties, of uniform action. It is truly one of the unchanging factors of the environment, to which living organisms necessarily react, for their composition, structure, nutrition, and activities depend upon it.

We come now to consider the effect of gravitation. The force of gravity acts upon every particle of ponderable matter on the earth as a direct pull toward the center of the earth. This pull is equal, at the surface of the earth, to 32.2 foot seconds^2, *i. e.* a body at the surface of the earth would fall in a vacuum at a rate increasing 32.2 feet a second per second. The force of gravity, operating upon every particle of ponderable matter, constantly exerts upon it this uniform force. The force increases or decreases inversely as the squares of the distances. But, as Newton showed, the force of gravity is not merely the attraction between the earth as a whole and other ponderable matters, but every portion of matter attracts every other portion with a force proportional to the product of their masses divided by the square of their distances apart.[1] The sum of the attractions toward the center of the earth equals the amount previously mentioned, 32.2 foot seconds^2, and this sum we may for the moment speak of as gravity without necessarily taking its components into account.

[1] Watson, W. *A Textbook of Physics*, p. 121. New York, 1900.

The attraction of gravity upon all ponderable matters is, however, opposed by the media in which they are. This is implied by the statement of the value of gravity at the earth's surface, for this statement specifies *in vacuo*. Every ponderable body is bouyed up (or supported) by a force equal to the weight of the fluid it displaces. This law of Archimedes concerns us as it applies to the air and to both fresh and salt water. Besides this we have the solidity and comparative impenetrability of the earth itself to reckon with, for the soil is capable of mechanically supporting much more than the weight of the parts of plants and animals resting upon or within it. Gravity is then opposed, partly or wholly, according to the medium in which the attracted object is.

The opposition to gravity varies from .0013 gr. per cc. in air at 0° C., and at ordinary atmospheric pressure, through 1.00 gr. per cc. in pure water and 1.20 gr. in sea water, to much more than the weight per cc. of any of the substances with which we ordinarily have to deal. Thus if we have a plant or animal or any other portion of matter weighing x grams in air, this matter would have a weight in pure water equal to x minus 1 gram for every cc. of volume. In sea water this would be $x - 1.2\ y$, in which y represents the number of cc. in the portion of matter. To take a concrete instance, suppose we have a block of wood, occupying a space of 9 cc. and weighing 10 gr. in air. This would weigh in water $10 - 1 \times 9 = 1$ gr.; in sea water this would be $10 - 1.2 \times 9 = 0.8$ gr. or, in other words, the block would float. In the same way the block would be completely supported, gravity would be completely offset, if the block were on or in the soil. But as the soil, the water, and the air do not come into direct contact with and are therefore not displaced by each individual part and particle of a portion of matter, there must be enough mechanical strength within the portion of matter to resist the force of gravity or the body would fall to pieces. We see then that though a body as a whole may be bouyed up by a considerable force which resists gravity, the component particles of the body are not necessarily so bouyed up but are subjected to the full attraction of gravity. Although the bouyancy of the medium in which a plant lives makes a very great difference in the mechanical strength of the plant as a whole,[1] there is no discoverable difference in the structure and other properties of the protoplasm. This fact is what the foregoing discussion has lead us to expect; for upon the component particles of protoplasm the force of gravity operates unopposed by the bouyancy of air or water, except such water as is in the cell-sap; and as the force of gravity is continuous and uniform in operation, the living protoplasm is subjected to a continuous and uniform influence. Does it not react accordingly?

Again, the force of gravity, regarded both as the attraction of the earth as a whole as well as the attraction of each particle of matter for every other, has never been eliminated from any experiment. If it had been, can we imagine what would have happened? The force of gravity acts only in one direction. The slow revolution of a plant upon a horizontal axis by means of a clinostat, so that all its parts will be successively turned in this direction, and the opposition of centrifugal or other force to the force of gravity, yield interesting results in experiments in which these methods are employed, but they throw little or no light on the influence of gravity upon the component parts of the living structure. Until gravity is eliminated, not merely opposed, we cannot even guess what its influence is; but rather than ignore it, we may guess that its influence as a formative agent is as great as we now know its directive influence to be. And as we know that its directive influence is always the same, that plants of a kind under like conditions respond in approximately like ways, like times, and with like force to the action of gravity, sending their roots downward into the soil and their stems upward into the air, we must infer that in the formation of new protoplasm the component parts of this structure are affected always in the same way and that they respond to the constant and uniform force in constant and uniform ways.

It remains to add a word as to the earth as a whole as one of the continuous and uniform factors of the environment of living organisms. The earth is a spheroid whirling in space at a rate decreasing with inconceivable slowness. Its position with relation to other bodies of the solar and other planetary systems changes also with inconceivable slowness. It possesses a degree and a distribution of heat throughout its mass which changes also with wonderful slowness. The earth possesses size, structure, composition, compactness, and other physical and chemical properties which change so slowly that in the lapse of ages differences can scarcely be detected, and millions of generations come and go under exactly like influences.

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[1] Peirce, G. J. A comparison of land and water plants. *Pop. Sci. Monthly*, LXIII, p. 239, 1903.

Passing now from these unchanging factors to the living organism itself, we must see that every particle of protoplasm is affected by the components and by the properties of the atmosphere, by the physical and chemical qualities of water, by the force of gravity, and by the earth as a whole. Every particle of protoplasm since it came into existence as such, every molecule of every compound in it, and every atom in the molecule, has existed from its beginning on this earth under these conditions and subject to these influences. None of these influences has ever been eliminated by experiment, nor has experiment ever resulted in accomplishing any fundamental change in a living organism or series of living organisms. Man as an experimenter cannot control these influences but is controlled by them. Is he not controlled by them in every other relation in life? Is man any more controlled by these unchanging influences than any other living or lifeless thing?

In the living substance of sperm and egg the component parts, particles, molecules, and atoms, have been subjected to these unchanging forces, not only since coming together as the living structure, but before; and after sperm and egg fuse the same is true; and in the growth of the fertilized egg every particle of new material is formed, placed, and kept in place under these influences. From the beginning to the end of its career every individual plant and animal is subjected to these continuous and uniform influences. But so also is every other thing. And as we find all common salt crystals behaving alike and being fundamentally alike at the same time that they are unlike the crystals of all other substances subjected to these same influences, so we find the plants or animals of a kind behaving and being in the main alike at the same time that they are unlike the plants and animals of all other kinds, although they are subjected to the same influences. In the diversity of composition and adjustment to these forces we have a physical reason for the diversity of behavior of different animals, plants, and lifeless things. They are all influenced by these forces; what they are represents their reactions to these and to other forces. The fundamental likeness of parent and offspring represents the continuity of substance and of influence; the superficial differences represent the different influences to which they have been subjected and to which they have reacted. Not all common salt crystals are of exactly the same size. Not all the puppies of a litter are exactly alike. But the salt crystals are fundamentally alike, and so are the puppies. With their vastly greater complexity — considered merely chemically for the moment — one should expect puppies to vary more than salt crystals. But neither salt crystals nor puppies vary so far as not to be salt crystals or puppies; the continuous influences conserve their fundamental characters.

In this discussion two things have been assumed — the continuity of substance from parent to offspring, and the irritability the power of reaction, of this substance to the various factors of its environment. These two facts are essential to heredity. My contention is merely that in the continuous, unchanging factors of the environment we have forces, influences, stimuli, under the operation of which the living substance came into existence, under which it continues to exist, and to which it continuously and unchangingly reacts. These influences are factors in the environment, but at the same time, like irritability, they are factors in heredity. The clearer our conception and the fuller our knowledge of the irritability and the power of reaction of living organisms to external stimuli, the smaller the mass of unexplained though not unexplainable phenomena for which we shall make heredity accountable.

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